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Optimization and application of process parameters in an AZ61 alloy twin-roll strip casting

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Abstract

Twin-roll strip casting is a concerned technology for economically producing magnesium alloys sheets. In this paper, numerical simulation of the twin-roll strip casting of an AZ61 magnesium alloy was carried out and the optimal process parameters were obtained. Then, under the conditions obtained through simulation, AZ61 strips of good surface quality were successfully manufactured. The microstructure of the alloy by twin-rolled strip casting is obvious refined compared with that by conventional casting.

Keywords

casting, strip, roll, twin, application, alloy, optimization, az61, parameters, process

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Optimization and Application of Process Parameters in an AZ61 Alloy Twin-Roll Strip Casting

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Key words： AZ61 Alloy; Twin-Roll Strip Casting; Microstructure

Abstract. Twin-roll strip casting is a concerned technology for economically producing magnesium alloys sheets. In this paper, numerical simulation of the twin-roll strip casting of an AZ61 magnesium alloy was carried out and the optimal process parameters were obtained. Then, under the conditions obtained through simulation, AZ61 strips of good surface quality were successfully manufactured. The microstructure of the alloy by twin-rolled strip casting is obvious refined compared with that by conventional casting.

Introduction

The twin-roll strip casting was first conceived by Henry Bessemer in 1856. The biggest advantage of twin-roll strip casting technology is that it enables magnesium alloy strips to be produced directly from molten melt with a thickness at near-net-shape, thereby reducing capital investment and operational costs compared to conventional processes. Due to its advantages, twin-roll strip casting has become more and more important during the last 40 years.

Liang and Cowley [1] described the challenges faced in producing of magnesium alloy strips by twin-roll strip casting. Engl [2] reported that magnesium strips with a thickness of 4.5-7 mm were produced at competitive prices with the aid of twin-roll strip casting. Mino et al. [3] casted an AZ61 strip by twin-roll caster and investigated the effects of casting conditions and rolling parameters on surface aspects. Watari et al. [4] also investigated the appropriate twin-roll strip casting manufacturing conditions of an AZ61 magnesium alloy.

Different numerical models are presented by various authors. Buechner [5] proposed a model to investigate the correlations between feeding system and strip quality. Miao et al. [6] developed a coupled three-dimensional flow and heat transfer model to simulate the twin-roll strip casting process by the finite element method. Zeng et al. [7] developed a CFD model for the numerical simulation of Mg twin-roll strip casting process. The distribution of temperature and flow fields in cast-rolling zone was obtained through the direct coupled solution of finite element method [8].

This work optimizes the process parameters used in twin-roll strip casting of an AZ61 magnesium alloy through numerical simulation. Then, under the obtained conditions, experiments of twin-roll strip casting of an AZ61 alloy were successfully carried out.

Numerical Simulation

In twin-roll strip casting, several process parameters have important implication on successful run, such as pouring temperature, casting velocity, length of roll-casting zone and roller gap. These parameters involve solidification of melt and formation of strip. A certain range of parameters can make strip casting process carry out successfully. Too high or too low may both bad affect this process and result in unsuccess. The aim of numerical simulation is to find the range or the optimal value of each parameter.

Simulation model. The simulated physical model was magnesium melt in nozzle and roll-casting zone. The dimensions of nozzle and roll-casting zone are shown in Fig. 1. Due to the physical model was asymmetrical model, for the aim of facilitating the calculation, a quarter of overall model was chosen for computational domain on platform of ANSYS. Eight-node FLUID142 fluid element in ANSYS was adopted and uniform hexahedral mesh generation was carried out.

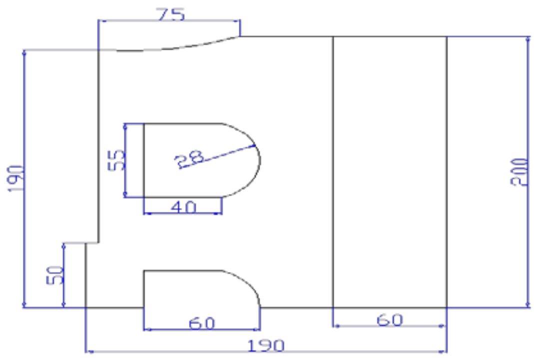


Fig. 1 Model dimensions

In the physical model, the initial temperature (pouring temperature) was set to 700 °C; the initial velocity was set to 2.2 m/min in the X direction and zero in the Y and Z directions; the initial length of roll-casting zone was set to 70 mm; the initial roller gap was set to 3 mm; the initial pressure was set to zero. Then, the resulted temperature fields were used as initial conditions of physical models with changed process parameters.

The boundary conditions of finite element model were set as following. In the entrance of nozzle, velocity boundary condition of X direction was set to 2.2 m/min and velocity boundary conditions of Y and Z were set to zero. At the same time, temperature boundary condition was imposed on the entrance of nozzle and the value was as same as the pouring temperature. In addition, in the X-Y plane and X-Z plane, velocity symmetric boundary condition was imposed. In the Z direction of X-Y plane and Y direction of X-Z plane, velocities were set to zero. In the sidewall of nozzle, roll-casting zone and spacer, stationary wall boundary condition was imposed. This referred to velocity of zero in all directions. In the entrance of roll-casting zone, velocity boundary condition of X direction was imposed and the value was equal to casting velocity and the velocities of Y and Z directions were set to zero. Furthermore, peripheral speed was imposed on contact surface of rollers and the magnesium alloy melt. Considering heat transfer of rollers and the magnesium alloy melt was convective heat transfer, neglecting radiative heat transfer, third boundary condition was imposed on the contact surface, namely certain temperature and convective heat transfer coefficient. Because this temperature affected by roller temperature, coupling calculation of roller and the magnesium alloy melt was used to amend the contact surface temperature. The application method of convective heat transfer coefficient was following. First of all, a constant convective heat transfer coefficient was imposed on entire contact surface to calculate roughly and approximate location of solidification end point in roll-casting zone was obtained. Then, this solidification end point as boundary, a smaller convective heat transfer coefficient was set to the complete solidification part of contact surface and a larger convective heat transfer coefficient was set to liquid phase and two-phase region. The set of rollers was following. The initial temperature was room temperature. The velocity boundary condition was imposed on outer surface of rollers and the value was equal to casting velocity. Thermal radiation was imposed on outer surface of rollers which were contacting with air. Third boundary condition was imposed on inner surface of rollers which were contacting with cooling water. The temperature was water-cooled temperature and the convective heat transfer coefficient was 10000 $W \cdot m^{-2} \cdot °C^{-1}$. Third boundary condition was also imposed on outer surface of rollers which were contacting with the magnesium alloy melt.

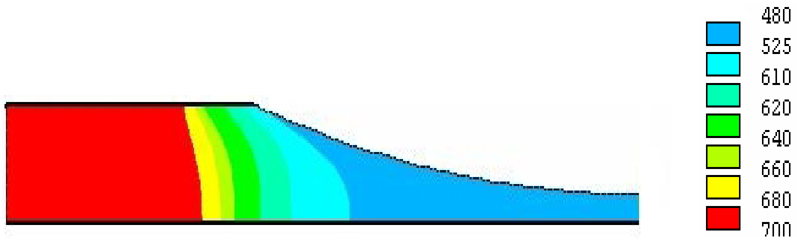
The entire calculation processes mainly consisted of the following steps.

(1) Under the initial conditions, firstly coupling calculation of flow fields and temperature fields of the magnesium alloy melt in nozzle and roll-casting zone was carried out; then the temperature field of rollers was calculated; finally coupling calculation of rollers and the magnesium alloy melt was conducted. Until flow fields and temperature fields both reached stable, namely the change of component values of temperature and velocity of all element nodes in the range of 0.1% within next time step, the system was considered to reach equilibrium state.

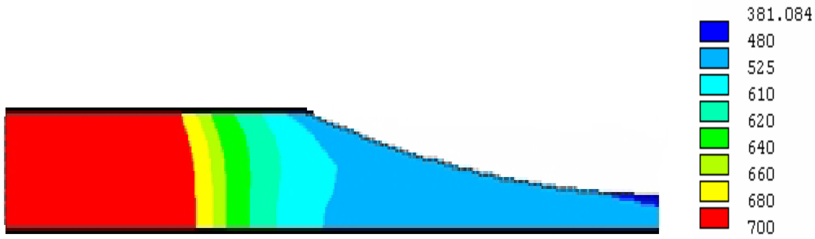
(2) Final results obtained through above step, namely final temperature fields, final flow fields and final stress fields, were used as initial conditions of recalculation with changed process parameters. Then calculation was carried out according to above method, and flow fields and temperature fields under different process parameters were obtained.

In this paper, the effect of length of roll-casting zone and roller gap on strip casting process is the key discussed issues.

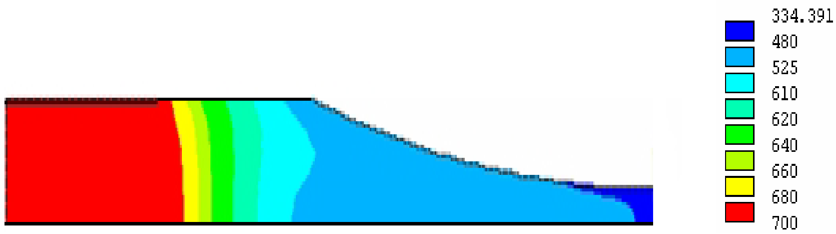
Results and discussion. The suitable pouring temperature and casting speed of twin-roll strip casting for AZ61 magnesium alloys have been discussed in Ref. 9 and the optimal range is 690 °C~710 °C and 2.0 m/min~2.4 m/min. In this paper, the optimal length of roll-casting zone and roller gap are discussed at the conditions of pouring temperature of 700 °C and casting speed of 2.2 m/min.



(a) L=70 mm



(b) L=80 mm

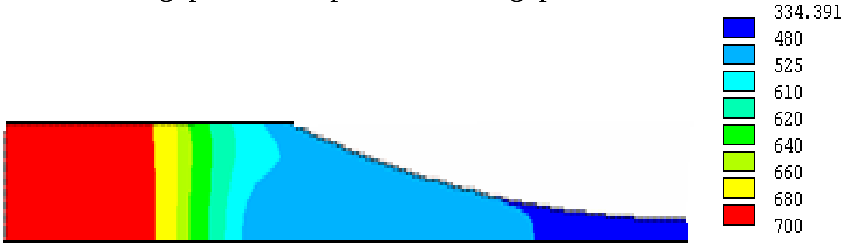


(c) L=85 mm

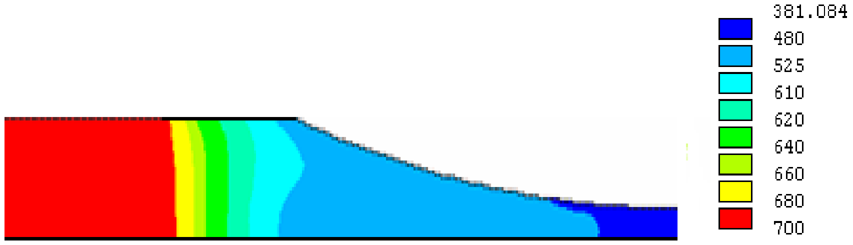
Fig. 2 Temperature fields at the different lengths of roll-casting zone

Fig. 2 shows the temperature fields of roll-casting zone in the different lengths of roll-casting zone. The lengths of roll-casting zone are 70 mm, 80 mm and 85 mm in Fig. 2(a), (b) and (c) respectively. It can be seen that the final solidification point moves from exit end to the position of about 6 mm from exit end with the increase of length of roll-casting zone from 70 mm to 85 mm. The main reason is that contact surface between the melt and rollers increases with the increase of length of roll-casting zone, and this strengthens cooling capability during the roll casting process and results left movement of the complete solidification point. In the process of twin-roll strip casting of AZ61 alloy, the condition of forming strip from melt is the certain thickness solidification layer in exit end. But large thickness solidification layer before exit end can make the strip withstand large rolling force and this result in easy crack formation. So, the optimal length of roll-casting zone is 80 mm.

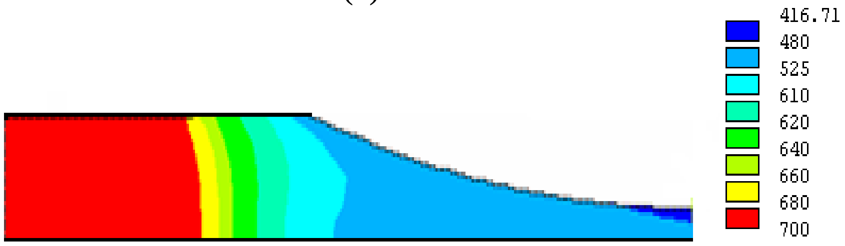
Temperature fields of the roll-casting zone under various roller gaps are shown in Fig. 3, where the roller gaps between rollers are 3 mm, 4 mm and 5 mm in Fig. 3(a), (b) and (c) respectively. It can be seen that the final solidification point has a relatively large right movement with the increase of roller gap. The final solidification point moves from the position of about 24 mm from exit end to exit end. This shows that the position of solidification point is sensitive to the change of roller gap. The strip formation needs certain thickness solidification layer, but too thickness solidification layer makes strip withstand large rolling force and results in easy formation of cracks. Twin-roll strip casting is a near net shape technology, thin strips are expected to successfully manufacture to reduce the subsequent process operations. In this case, the thinnest strip informed through simulation the optimal roller gap is the strip when roller gap is 5 mm.



(a) Δ=3 mm



(b) Δ=4 mm



(c) Δ=5 mm

Fig. 3 Temperature fields at the different roller gaps

Experimental

The experimental devices include melting furnace, nozzle and reversible twin-roll strip caster. The hearth of melting furnace is made of heat-resistant steel. An orifice was set near the bottom of hearth. A certain distance between orifice and hearth can avoid impurities entering nozzle. At the top of melting furnace, a sealing cover with a hole was set to make shielding gas enter furnace.

Table 1 Technical parameters of twin-roll strip caster

Diameter of upper roller	Diameter of lower roller	Minimum casting speed	Maximum casting speed
500 mm	500 mm	0.5 m/min	7 m/min

The twin-roll strip caster has two counter-rotating rollers, which are water cooled from inside. Roller shell is made of heat-resistant alloy steel. Roller gap is adjusted through hydraulic pressure. The reversible twin-roll strip caster is shown in Fig. 4 and its technical parameters are showed in Table 1.

Fig. 4 Reversible twin-roll strip caster

An AZ61 magnesium alloy was used in twin-roll strip casting experiments. The chemical composition is Al 6%, Zn 1.0%, Mn 0.2% and Mg the rest. In this experiment, the process parameters obtained through simulation, pouring temperature 700 °C, casting speed 2.2 m/min, length of roll-casting 80 mm and roller gap 5 mm were used. Firstly, commercially pure magnesium and aluminum were put in melting furnace and heated to melt completely. In the heating process, the melt was in the protective atmosphere of SF_6 and CO_2 gas mixture. Then, commercially pure zinc and Al-9%Mn master alloy was added into the melt. After stirring uniformly, 0.2% Ca was added into the magnesium alloy liquid to achieve effective flame-retardant of the melt. Furnace temperature was controlled in the range of 680 °C ~750 °C, then standing and filtration was carried out in turn. When temperature reached 700 °C, twin-roll strip casting experiment was operated at the speed of 2.2 m/min. In the experiment, rolling pre-pressure was 7 MPa, water pressure of roller was 0.2 MPa, and water flow was 5 m^3/h.

Fig. 5 shows the strip of AZ61 obtained at pouring temperature of 700 °C and casting velocity of 2.2 m/min. It can be seen that strip of good surface quality was successfully produced.

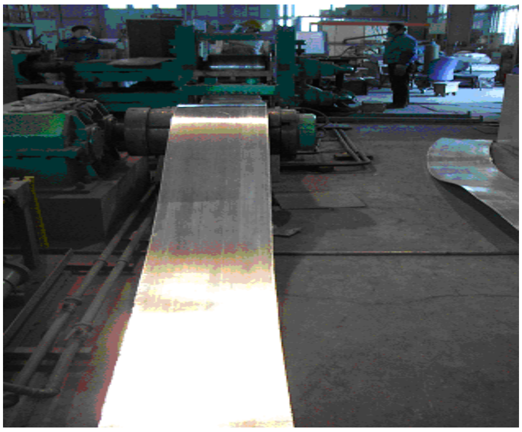


Fig. 5 The strip of AZ61 by twin-roll strip casting

Fig. 6 shows the microstructure graph of the conventional casting and roll-casting samples. Due to different processing methods and solidification conditions, two kinds of microstructure characteristics have large difference. Fig. 6(a) and (b) are center and edge microstructures of AZ61alloy under the condition of conventional casting. Grain shape is very uneven, dendrites are strong in the center, and the average size of center grains is larger than that of edge. However, after roll casting, microstructures of AZ61 alloy consist of small dendrites, shown as Fig. 6(c) and (d), grain size has little difference between center and edge. The most obvious is that microstructures obtained by roll casting are smaller and evener than that of conventional casting.

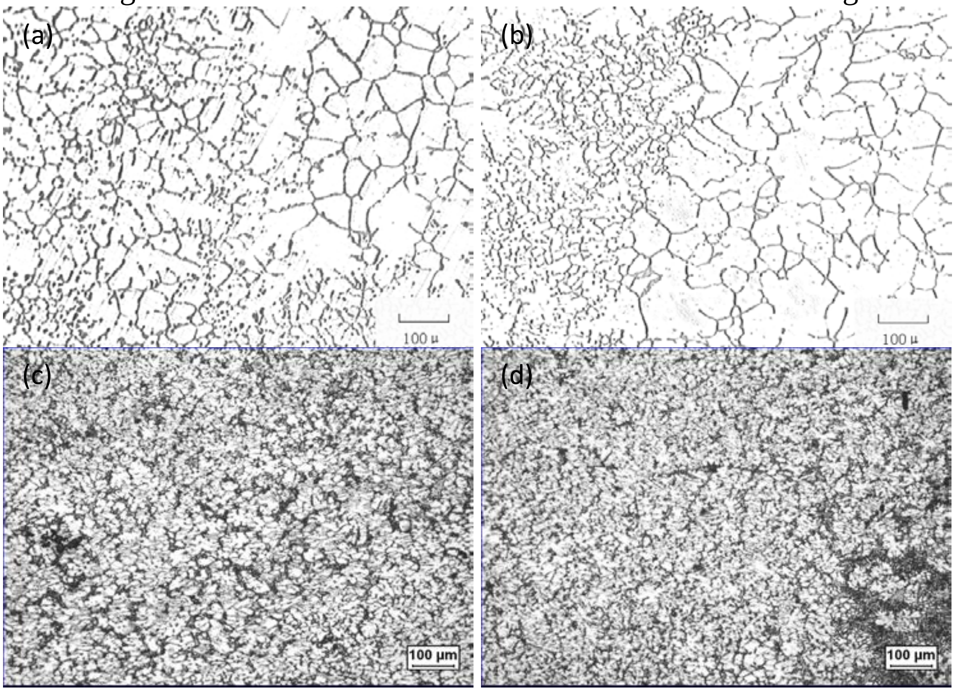


Fig. 6 The microstructures of conventional casting and roll casting of AZ61 alloy
(a) Conventional casting, center; (b) conventional casting, edge;
(c) roll casting, center; (d) roll casting, edge

Through optimizing the process parameters by numerical simulation, the good quality magnesium alloy strips were manufactured. This indicates that the method of numerical simulation can be used to optimize and design the roll casting process of magnesium alloys.

Conclusions

(1) The optimal process parameters were obtained through numerical simulation. Under the conditions, the optimal length of roll-casting zone is 80 mm and the optimal roller gap is 5 mm.

(2) Using the optimized process parameters, good quality strips were manufactured. Microstructures of roll casting are smaller and evener than that of conventional casting.

(3) The fact experiment was carried out successfully using process parameters obtained by simulation indicates numerical simulation is helpful for optimizing the process parameters of twin-roll strip casting of magnesium alloys.

References

[1] D. Liang and C.B. Cowley: JOM Vol. 56 (2004), pp. 26-8.
[2] B. Engl: Light Metal Age Vol. 63 (2005), pp.14-9.
[3] T. Mino, M. Asakawa, D. Lee, T. Fujiwara, K. Matsuzaki and M. Kobayashi: J. Mater. Process. Technol. Vol. 177 (2006), pp. 534-8.
[4] H. Watari, T. Haga, N. Koga and K. Davey: J. Mater. Process. Technol. Vols. 192-193 (2007), pp. 300-5.
[5] A.R. Buechner: Steel Res. Vol. 75 (2004), pp. 5-12.
[6] Y.C. Miao, X.M. Zhang, H.S. Di and G.D. Wang: J. Mater. Process. Technol. Vol. 174 (2006), pp. 7-13.
[7] J. Zeng, R. Koitzsch, H. Pferfer and B. Friedrich: J. Mater. Process. Technol. Vol. 209 (2009), pp. 2321-8.
[8] H. Zhao, P.J. Li and L.J. He: J. Mater. Process. Technol. Vol. 211 (2011), pp. 1197-202.
[9] J.T. Li, G.M. Xu, H.L. Yu, G.Y. Deng, C. Lu, L.Z. He and H.J. Li: Northeastern University, Shenyang, unpublished research, 2012.